

## Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.



Issued July 27, 1907.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 42.

MILTON WHITNEY, Chief.

---

RECLAMATION OF WHITE-ASH LANDS  
AFFECTED WITH ALKALI AT  
FRESNO, CALIFORNIA.

BY

W. W. MACKIE.



WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1907.

## BUREAU OF SOILS.

---

MILTON WHITNEY, *Chief of Bureau.*

ALBERT G. RICE, *Chief Clerk.*

## SCIENTIFIC STAFF.

FRANK K. CAMERON, in charge of Soil Laboratories.

FRANK D. GARDNER, in charge of Soil Management.

GEORGE T. MCNESS, in charge of Tobacco Investigations.

CLARENCE W. DORSEY, in charge of Alkali Land Reclamation.

JAY A. BONSTEEL, in charge of Soil Survey.

OSWALD SCHREINER, in charge of Fertility Investigations.

W J MCGEE, in charge of Soil Erosion Investigations.

## LETTER OF TRANSMITTAL

---

U. S. DEPARTMENT OF AGRICULTURE,  
BUREAU OF SOILS,  
*Washington, D. C., April 24, 1907.*

SIR: I transmit herewith a paper by Mr. W. W. Mackie, entitled Reclamation of White-Ash Lands Affected with Alkali at Fresno, California.

This paper discusses broadly, and mainly in untechnical language, the various questions entering into the problem of alkali land reclamation in the locality named. It includes the final results of the Bureau's work on the Toft-Hansen reclamation tract, where the redemption of lands from a nonproductive state to a condition making their use highly profitable has been successfully carried out.

This paper has been gone over carefully with Assistant Secretary Hays, who authorizes me to state that he concurs in my recommendation for its publication. This will be number 42 of the series of bulletins issued by the Bureau.

Very respectfully,

MILTON WHITNEY,  
*Chief of Bureau.*

HON. JAMES WILSON,  
*Secretary of Agriculture.*



## CONTENTS.

---

	Page.
Introduction.....	7
Soils affected with alkali.....	12
Hardpan.....	13
Origin, composition, and movement of alkali.....	14
The effect of alkali on plants.....	17
Crops adapted to alkali soils.....	18
Demonstration work on the Toft-Hansen tract.....	20
Flooding vineyards for alkali burn.....	23
Ground water.....	26
Annual fluctuation of ground water.....	27
Effect of drainage on the water table.....	28
Composition of ground water.....	30
Use of ground water for irrigation.....	32
Effect of drainage water upon canal water.....	33
Other methods of alkali reclamation practiced at Fresno.....	35
Use of gypsum.....	35
Constant tillage.....	37
Incorporating barnyard manure.....	37
Blasting hardpan.....	37
Surface flushing.....	37
Flooding without underdrainage.....	38
Recommendations for reclaiming lands at Fresno.....	39
Depth of flood water.....	41
Flooding vineyards in alkali soils.....	43
Summary.....	43
Appendix:	
Plants used as alkali land indicators.....	45

## ILLUSTRATIONS.

---

	Page.
FIG. 1. Sketch map showing areas of alkali land near Fresno.....	8
2. Plan of drains, Toft-Hansen tract.....	23



# RECLAMATION OF WHITE-ASH LANDS AFFECTED WITH ALKALI AT FRESNO, CALIFORNIA.

---

## INTRODUCTION.

The present paper is written to show those farmers owning alkali land what treatment is necessary to make these lands as productive as the finest lands in the Fresno district. In discussing the relations of the soils of the Fresno district to alkali, however, it should be clearly borne in mind that only limited areas of those soils underlain by white hardpan are affected with alkali. The soils underlain by red hardpan contain but little alkali, and there is practically no danger that any serious damage from this source will ever result, and it is upon these alkali-free soils that the agricultural prosperity of Fresno has been firmly established. The accompanying sketch map (fig. 1) shows the position of the lands underlain by red hardpan and white hardpan and the areas of white hardpan soils affected with alkali. Of the 400,000 acres comprising the Fresno district 64,000 contain some alkali, but only 28,000 acres contain sufficient to prevent the growth of any useful crops. The remaining 36,000 acres contain only moderate quantities of the injurious salts and even in their present condition can be farmed with a fair degree of profit.

The country about Fresno is a vast plain intersected by the San Joaquin and Kings rivers and their tributaries. Before the advent of the Southern Pacific Company in 1876 the land was used for grazing purposes only, and many herds of cattle and sheep fattened on the native grasses and shrubs. These consisted mainly of foxtail or barley grass, salt grass, bunch grass, broncho grass, and filaree (*Erodium*).

The soils at this time were popularly classed as follows: The "red" soils, lying near the hills, the "white-ash" soils, found farther out in the plain, and the "white sands," or the extremely sandy soils associated with the white-ash soils. Where hardpan did not occur too near the surface the red soils were considered the best soils for all crops. The white-ash soils were not considered to have so wide an adaptation, but grew immense crops of grain and alfalfa. The sands or sandy soils were considered very poor and fit only for dry-farmed grain crops in wet years.

With the extension of the railroad system through the San Joaquin Valley, connecting San Francisco with the south and east, began the agricultural development of the Fresno region. At first grain crops only were grown, depending entirely on the annual rainfall, but recurring droughts soon forced upon the settlers the use of irrigation and the discovery that better and more remunerative crops than grain could be easily grown. Alfalfa fields soon produced green summer pasture and immense crops of hay as well. The small family orchard and vineyard of the settler were so fruitful that they were rapidly extended, and thus the fruit industry, which now overshadows all others, became paramount.

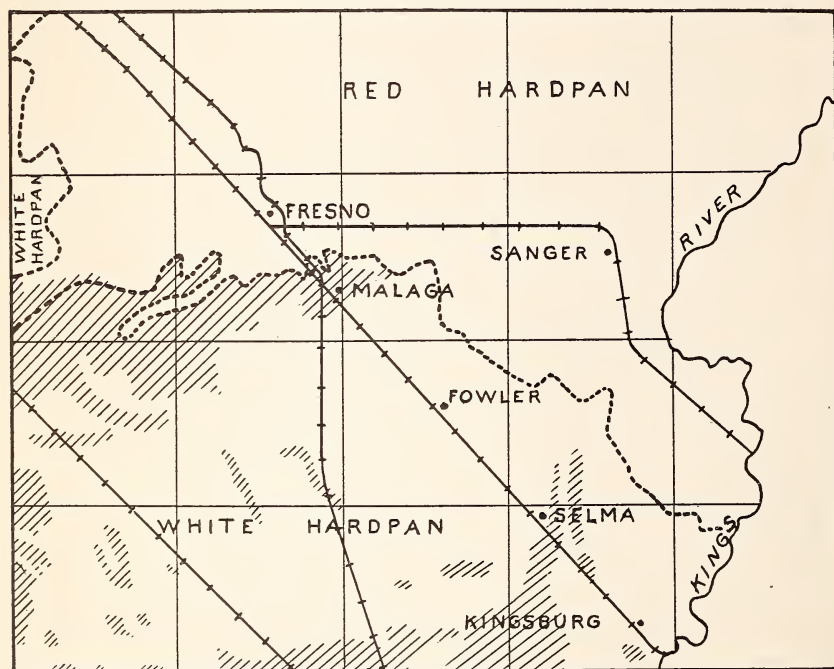


FIG. 1.—Sketch map showing areas of alkali land near Fresno.

The raisin grape, although grown at earlier dates in several parts of California, was soon cultivated at Fresno, especially in small vineyards. The first extensive plantings of Muscat grapes on the rich, level white-ash lands 3 miles southwest of Fresno proved so exceedingly profitable that a veritable rush began into raisin vineyards. Very soon an area of white-ash lands comprising about 20,000 acres to the southwest of Fresno was divided into small holdings, containing from 10 to 40 acres, devoted chiefly to vineyards, orchards, and alfalfa fields. Abundance of water from Kings River was assured, crops were good, and prices high. This full tide of prosperity continued until 1888 or 1890.

Alkali had always been present in the lower depths of the soil, but was visible only in isolated spots. It now began to appear in increasing and dangerous quantities on the surface. This rise or spread of alkali was due entirely to the rise and spread of the ground water.

Mr. Gustav Eisen, one of the earlier settlers on the red lands east of Fresno, states in his paper on the "Culture of the Grape in California,"<sup>a</sup> that in 1873, when irrigation water was first taken from Kings River, the water table was 65 feet deep, but that in 1878, after five years of irrigation, water stood at 6 feet from the surface of the soil.

In 1888, on the white-ash lands, the water table fluctuated between 2 or 3 feet from the surface in the spring growing season and 8 or 10 feet in the winter season. This water as it rose from the lower depths carried with it the alkali salts contained in the soil and upon evaporation from the surface the salts were concentrated within the zone of the tender rootlets of the annual crops. The concentration in alkali became exceptionally high in the surface foot of soil, thus preventing the germination of seeds. The caustic black alkali also burnt the young rootlets of the perennial plants.

The raisin vineyards first showed the evil effects of alkali by loss in crop yield, by less vigorous growth, and finally by burning and shedding of leaves in summer. On account of the proximity of hardpan to the surface in places where the soil is of heavier texture alkali had accumulated in greater quantities in these spots, and the vines soon died, while even in the surrounding vineyards where the vines were not killed the crops were so greatly reduced in quantity and quality that it became unprofitable to cultivate and harvest them.

Finally, about 1890, overproduction, financial stringency, and Spanish competition caused the price of raisins to drop so low that the crops barely paid for their production even in good vineyards. Hundreds of acres of vines were dug up and the land was replanted to alfalfa in the sweeter soils and to Bermuda grass where there was more alkali.

The decline of the raisin industry extended to 1898, when prices increased so that the cultivation of raisins became profitable again. Replanting began on an extended scale in the higher alkali-free lands nearer the Sierra Nevada Mountains, but few cared to replant on the white-ash lands, which were more susceptible to alkali damage. Because the area of good lands was limited, prices became almost prohibitive, with the result that the white-ash lands again came into notice.

During the period of rapid alkali encroachment many efforts were made to find remedies for the prevention and cure of the evil. The

---

<sup>a</sup>American Grape Growing and Wine Making, by Geo. Husmann.

University of California<sup>a</sup> advised the reclamation of alkali land by heavy flooding to drive down the salts and underdrainage to remove them. The use of gypsum was also recommended to correct the caustic black alkali by transforming it into the neutral sodium sulphate or white alkali. The hardpan was given as the source of black alkali, and it was thought that gypsum would soften and disintegrate it until it would become pervious to water and roots. Farmers who applied gypsum to their lands derived no permanent benefit, for the black alkali and hardpan continued to exist where gypsum had been plentifully used. Underdrainage was not attempted on account of the nearly level character of the country and the shallow water table.

In 1900 the Bureau of Soils surveyed the Fresno district, including the white-ash lands affected by the rise of alkali, and constructed and published<sup>b</sup> soil, hardpan, and alkali maps. It was found that the white-ash soil, called Fresno sandy loam, of which 69,811 acres were mapped, contained the larger proportion of alkali found in the Fresno district, and that the Fresno sand, covering an area of 163,200 acres, had, through improper methods of irrigation, also become affected over considerable areas, the white hardpan and alkali occurring some distance below the surface. The area mapped in 1900 in the Fresno survey was 401,855 acres. The following table shows the extent of land of the several grades of alkali:

*Areas of the different alkali soils.*

Grades of alkali soils.	Acres.	Per cent.
0 to 0.20 per cent alkali.....	336,300	83.8
0.20 to 0.40 per cent alkali.....	26,300	6.6
0.40 to 0.60 per cent alkali.....	10,150	2.5
More than 0.60 per cent alkali.....	28,500	7.0
Total area.....	401,250	.....

These four grades for alkali soils are purely arbitrary. They are based on the average percentage of soluble salts in the soil to a depth of 5 feet. The relations of the several grades to crops are as follows: Those soils containing quantities of alkali up to 0.20 per cent are classed as alkali-free soils, such small quantities having no injurious action upon any crops. Upon lands of the next grade, those containing from 0.20 to 0.40 per cent of alkali, alfalfa and grain may often be profitably grown, but vines and trees suffer. Lands of the next grade—0.40 to 0.60 per cent—contain too much alkali for profitable crops, but when sufficiently moist they will grow Bermuda grass and certain hardy trees, like willow, cottonwood, eucalyptus, pomegranate, and fig. The last grade includes all land

<sup>a</sup> Bulletin No. 83, Cal. Expt. Sta.

<sup>b</sup> Field Operations of the Bureau of Soils, 1900, pp. 333-384.

containing more than 0.60 per cent. The soils of this grade, under natural conditions, are worthless, except for a few weeds and salt grass, which afford scant pasturage, although when irrigated Bermuda grass thrives.

From a study of the conditions at the time of the Fresno survey it seems that about 30,000 acres of the white-ash lands southwest of Fresno, previously in a high state of cultivation, had been injured by rise of alkali and were unprofitable for fruit culture. The Bureau pointed out that the arrest and cure of the alkali damage should first be commenced on those lands. The report stated that the question of alkali was resolved into two problems: First, to prevent good lands from accumulating sufficient alkali to injure crops; second, to reclaim lands already seriously damaged by alkali. It was shown that if the capillary rise of the water is retarded or prevented, whereby evaporation at the surface is reduced to a minimum, accumulation of alkali at the surface will be lessened or entirely prevented. Lowering the water table by drainage restricts the upward capillary movement of soil water, and breaking up the capillary spaces by culture is also effective in preventing alkali accumulations in good lands. To reclaim lands already containing alkali, deep underdrainage with copious surface irrigation was strongly recommended. The farmers were urged to take up reclamation, since in the greater number of cases the work was seen to be practical, for reclaimed land is almost always strong and productive, and, in fact, frequently better than land originally free from excess of alkali salts.

Soon after the completion of the Fresno soil survey the Fresno chamber of commerce and some enterprising landowners undertook to demonstrate on a small scale the efficiency of underdrainage in reclaiming alkali land. Unforeseen difficulties, however, influenced the chamber of commerce to abandon the work and to call on the Bureau of Soils to carry it to completion, and accordingly, in the fall of 1902, the Bureau laid a drainage system over 20 acres of the Toft-Hansen tract. Continuous flooding was carried on until large quantities of alkali had been removed and the reclaimed tract, which had been growing profitable crops for some time, was turned over to the owners in 1906.

The foregoing paragraphs have sketched in general terms the conditions around Fresno which led the Bureau to the undertaking of reclamation work in this district. The detailed steps in the actual work of reclamation will be given later, but before passing to this detailed account of the methods employed and the difficulties met and overcome in treating this alkali land, a further statement of the alkali problem and a description of the soils affected by alkali will be given.

## SOILS AFFECTED WITH ALKALI.

In the report cited<sup>a</sup> four types of soil are designated as occurring within the alkali area. These are the Fresno sandy loam, locally known as white-ash land; the Fresno sand, the Fancher sandy loam, and the San Joaquin sandy loam. The Fresno sandy loam contained excessive amounts of alkali in all but a few places in the area. The other three types were much less affected.

The Fresno sandy loam occupies the level stretches of plain to the southward of Fresno, with a gradual slope toward the southwest. To outward appearance it is an ideal soil for irrigation. Where unaffected by alkali it is light gray in color, but where excessive amounts of organic matter and black alkali occur it is either brown or black. It is supposed to have been derived from volcanic ash. It is of loose texture, but forms clods when allowed to bake. At a depth varying from 2 to 5 feet white hardpan occurs, composed mainly of volcanic ash cemented together by calcium carbonate or lime. There are, however, enough fracture lines in the hardpan formation to allow sufficient percolation to secure good drainage under normal conditions. By excessive irrigation the water table has risen so high that alkali has been brought to the surface on this soil type. Capillary movement and evaporation of water have concentrated most of it in the surface foot, ruining the land for cropping. In those portions of this type lying between Selma and Sanger, where the water table has not yet risen high enough to cause injury, are found the finest orchards and vineyards in the country.

The Fresno sand occupies a position similar to the Fresno sandy loam, and is always found in close proximity to it. This type is a light-colored sand with just enough clay and silt in it to cause it to stand in banks. It is a rich productive soil, and was evidently washed over an area of white-ash soil and piled in uneven masses and hillocks, intersected by swales. Nearly always at depths varying from 3 to 8 feet the white ashy material of the Fresno sandy loam and white hardpan are found. On account of its great porosity, unevenness, and elevation above the surrounding types of soil it has been neglected, except where it comes in contact with other soils. In past years it was farmed to grain, but recurring droughts caused grain farming to be abandoned. Recently, however, the Fresno sand has been found to be excellent for peaches, alfalfa, peanuts, cantaloupes, and sweet potatoes. Pumps are being installed in many places to furnish irrigation water. On account of looseness of texture, frequent irrigation is necessary. As the water table on most of this type is below 10 feet at all times, very little alkali is found,

<sup>a</sup> Soil Survey Around Fresno. By Thomas H. Means and J. Garnett Holmes. Field Operations of the Bureau of Soils, 1900.

save where the white hardpan lies near the surface. Where the Fresno sand borders the Fresno fine sandy loam, the water table is often close to the surface, and ponds frequently appear. For these reasons, and especially as it is sold at a comparatively low figure, there has been a great demand for this land.

The Fancher sandy loam is a heavy sandy soil, in some cases approaching adobe in texture. It is a red soil which has been carried into the alkali area by streams and deposited in narrow bodies upon the white hardpan soil. It is usually more than 6 feet in depth over the hardpan and very uniform in texture. What little alkali it contains has been derived from the surrounding soils. This is one of the best fruit soils.

The San Joaquin sandy loam is a coarse red sandy loam underlain at 3 feet by red iron hardpan. It is free from alkali, except where it comes in contact with the Fresno sandy loam.

#### HARDPAN.

At Fresno there are two kinds of hardpan underlying the soils—the red and the white. Approximate boundaries between these two kinds of hardpan were given by Means in his alkali map of the area. (See sketch map, fig. 1, p. 8.) As stated in the introduction, the white hardpan area includes nearly all the alkali lands of the district about Fresno.

The red hardpan is a cemented sandy material, on the surface of which sheets of ferruginous character, showing a metallic luster, are often found. This hardpan, therefore, is really a ferruginous sandstone, and acts as such toward the penetration of roots and water.

The occurrence of white hardpan is very general. It extends in isolated bodies of various sizes from south of Bakersfield, in Kern County, at the southern end of the San Joaquin Valley, to Lathrop, in San Joaquin County, at the northern end. The greater proportion of it lies along the trough of the valley to the east of the San Joaquin River and Tulare and Kern lakes. It is intersected by streams from the Sierra Nevada Mountains which have washed it away, replacing or covering it with alluvial soils. In thickness it is much less than the red hardpan, varying from 2 inches to 5 feet in extreme cases. Quicksands or water-bearing sands usually occur below it. At greater depths beneath these sands other layers of white hardpan may be found. While the alkali east of the San Joaquin River is by no means confined to white hardpan soils, these hardpan areas contain the greater part of it. The surface of the hardpan is not parallel to the surface of the soil, for the overlying soil varies from 1 foot to many feet in depth. In thickness the hardpan increases toward the valley trough.

The white hardpan consists of silt, clay, and sand firmly cemented by carbonates of lime and magnesia and carries varying amounts of soluble salts. In places it is thin and broken, while in the thicker portions cracks often appear. Through these places water passes, and sometimes roots. As a body, however, it is practically impervious to water and roots of crops. When white hardpan is soaked in water for many weeks, it softens perceptibly and often becomes spongy, but although the hardpan softens during irrigation, it hardens again after the lowering of the water table in the fall. Chunks of it exposed to the sun and air for a year did not weather or break down perceptibly. In unirrigated lands alkali is found in large amounts immediately above this hardpan, though there are only small quantities in the overlying soil. In water-logged lands, on the other hand, the alkali usually associated with the hardpan has been carried up into the soil.

Hardpan seriously affects crops about Fresno in three ways—first, by interfering with the retention and conservation of moisture; second, by restricting the development of plant roots, which in most cases require 3 feet of soil, and, third, by causing the retention of alkali in the upper layers of the soil, ready to ascend to the surface, whenever poor methods of irrigation are practiced or the water table is raised. On account of the limited amount of soil, irrigation must be frequent to give crops the moisture conditions suitable for best growth, and yet too heavy irrigations drown or smother the roots.

#### ORIGIN, COMPOSITION, AND MOVEMENT OF ALKALI.

The alkali in the San Joaquin Valley, including that of the Fresno tract, is generally supposed to be the result of rock decomposition, which gives rise to the various soluble salts. These salts represent the last stage in the decomposition of the complex silicates, pyrites, and other minerals which make up rocks. In arid or semiarid regions like the San Joaquin Valley these salts are washed from the hills and are accumulated in the valley soils. The sulphates may be derived in part from the pyrites which on oxidation give rise to the various sulphates.

The alkali in the eastern side of the valley is contained mainly in the first few feet of soil. Black alkali is usually a prominent constituent in the salts of this region. The deep subsoil waters are uniformly low in injurious salts and are everywhere freely used for irrigation without the least danger. In the heavier phases of the alkali soils, especially where underlain at shallow depths by hard pan, alkali is accumulated and retained in quantity, as these soils are more resistant to leaching by flooding or rainfall. These conditions of origin and accumulation are particularly applicable to the alkali derived from

the Sierra Nevada Mountains and accumulated in the soils east of the central trough of the San Joaquin Valley.

The alkali in the soils west of this valley trough are derived mainly from the leaching of the decomposing shales and sandstones which constitute the bulk of the rocks which form the Coast Range. This alkali consists largely of sulphates and is found uniformly in the soil to a great depth. Though no hardpan has been found to exist west of the trough of the valley, the rainfall has been too light to wash away the alkali.

According to Cameron<sup>a</sup> the alkali at Fresno is formed mainly by reactions between the chlorides of sodium and potassium and the carbonates of calcium and magnesium, giving rise to calcium and magnesium chlorides and sodium carbonate (black alkali).

The following table, giving analyses of nine samples, shows the composition of the alkali at Fresno:

*Chemical analyses of alkali salts containing no sodium carbonate.*

Constituent.	4872. Sec. 19, T. 14 S., R. 22 E., crust.	4841. Sec. 25, T. 14 S., R. 18 E., 0 to 12 inches.	4681. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4835. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4689. Sec. 2, T. 15 S., R. 19 E., 0 to 12 inches.	4831. Sec. 3, T. 15 S., R. 19 E., 0 to 12 inches.	4829. Sec. 31, T. 14 S., R. 20 E., 0 to 12 inches.	4877. Sec. 8, T. 17 S., R. 21 E., 0 to 12 inches.	4888. Sec. 9, T. 17 S., R. 22 E., 0 to 24 inches.
Ions:	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Ca.....	18.71	12.59	1.60	9.51	Tr.	2.31	3.52	0.48	3.01
Mg.....	8.21	5.26	.74	3.30	Tr.	Tr.	Tr.	.16	.....
Na.....	5.34	15.56	31.11	21.28	33.78	32.41	28.74	33.77	34.19
K.....	.92	1.15	2.63	1.86	1.86	1.85	.59	1.81	.63
SO <sub>4</sub> .....	1.00	1.60	25.84	4.54	11.97	5.55	3.81	5.44	7.24
Cl.....	64.60	60.40	33.39	54.55	29.92	36.49	4.99	8.06	2.41
CO <sub>3</sub> .....	.....	.....	.....	.....	3.19	5.00	16.71	22.63	33.85
Conventional combinations:									
HCO <sub>3</sub> .....	1.31	3.44	4.69	4.96	19.28	16.29	41.64	27.65	18.66
PO <sub>4</sub> .....	.....	.....	.....	.....	Tr.	.....	.....	.....	.....
CaSO <sub>4</sub> .....	1.38	2.28	5.43	6.50	.....	8.13	5.28	1.40	10.28
CaCl <sub>2</sub> .....	50.64	34.61	.....	21.08	.....	.....	8.21	.....	.....
MgSO <sub>4</sub> .....	.....	.....	3.66	.....	.....	.....	.....	.75	.....
MgCl <sub>2</sub> .....	32.75	20.49	.....	12.81	.....	.....	.....	.....	.....
K <sub>2</sub> SO <sub>4</sub> .....	.....	.....	.....	.....	.....	.....	.....	.....	.....
KCl.....	1.74	2.05	4.97	3.51	3.46	3.51	1.17	3.47	1.15
Na <sub>2</sub> SO <sub>4</sub> .....	.....	.....	28.25	.....	17.69	.....	.....	5.50	.....
NaCl.....	12.32	35.77	51.23	49.39	46.68	57.31	7.04	10.72	3.04
Na <sub>2</sub> CO <sub>3</sub> .....	.....	.....	.....	.....	5.72	8.68	29.62	39.96	59.85
NaHCO <sub>3</sub> .....	1.77	4.79	6.46	6.81	26.45	22.37	48.68	38.00	25.68
PO <sub>4</sub> .....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Per cent soluble.....	4.61	.87	3.50	.97	1.50	1.08	.68	3.75	1.91

<sup>a</sup> Ca (HCO<sub>3</sub>)<sub>2</sub>.

Assuming the conventional combinations, it will be observed that sodium chloride forms over 25 per cent of the alkali of this area. The average of 30 analyses of Fresno alkali shows that the total quantity of chlorides is about the same as the total quantity of carbonates and bicarbonates, which were present in about equal amounts. The sulphates occur in widely varying amounts from a mere trace to 20 per cent—the average for white-ash lands is close to 7 or 8 per cent, but in most water-logged lands it averages about 3 per cent of the mixed

<sup>a</sup> Bul. No. 17, Bureau of Soils, p. 28.

salts. One reason for this small proportion in the water-logged lands is probably the action of bacteria and algæ, which decompose the sulphates of the soil, giving rise to sulphurous gases, which escape.

As the capillary movement of soil moisture brings alkali to the surface, the alkali concentrates at the surface of the soil. In unirrigated virgin soils black alkali is found in varying amounts from the surface down to the underlying hardpan, but in irrigated soils with a high water table black alkali is seldom found in quantities deeper than a few feet. Sodium chloride (common salt) rises to the surface very readily, but is much more readily leached out by rain and irrigation water than the black alkali. During the process of irrigation comparatively large quantities of sodium chloride are present in the first drainage waters. After considerable water has passed through the soil, common salt decreases to small proportions.

The change of carbonates to bicarbonates is brought about by the action of water and of carbon dioxide,<sup>a</sup> while the reverse change of bicarbonates to carbonates is brought about by aeration or by the action of heat, which drives off carbon dioxide again. The ratio of bicarbonates to carbonates is also dependent on the concentration. This change has been demonstrated by evaporating drainage waters containing at the beginning no normal carbonates by exposing it to the sun for six consecutive days, or until the volume<sup>b</sup> was reduced by 90 per cent. It was then found that there were approximately equivalent amounts of both carbonates present.

Cameron and Patten<sup>b</sup> percolated water through a black alkali soil. In the first percolates the normal carbonate was present, but on continued leaching soon disappeared entirely. The bicarbonates, however, continued to come out in considerable quantities, showing clearly that the carbonates reverted to bicarbonate in the presence of large quantities of water. These experiments agree with Hilgard's statement<sup>c</sup> that in order successfully to remove black alkali from the soil by leaching it is necessary to change sodium carbonate into another salt which is more readily leached.

Owing to its great absorption by soils, sodium carbonate tends to retain its position, while sodium bicarbonate seems to be absorbed to a much less degree. Moreover, bicarbonates are comparatively mild in their action toward seeds and plants, and in fact are far less injurious than the normal carbonates.<sup>d</sup>

The movements of alkali-carrying waters in the soil are varied. Immediately after rains the movement is downward because of the force of gravity. During irrigation by flooding this movement is also

---

<sup>a</sup> Bul. No. 18, Bureau of Soils, U. S. Dept. of Agr.

<sup>b</sup> Jour. Am. Chem. Soc., 28, 1646 (1906).

<sup>c</sup> California State Expt. Sta. Report, 1903, p. 65.

<sup>d</sup> Kearney and Cameron, Report No. 71, U. S. Dept. of Agr.

downward, but after flooding has ceased the ground water rises by capillary forces to compensate for evaporation at the surface. In this way alkali washed down in irrigation is again carried to the surface and the bicarbonates are reverted to carbonates as evaporation proceeds. The accumulation of salt at the surface is retarded when a mulch is formed, which hinders evaporation and the consequent capillary movement of moisture.

In order to determine how much alkali would return through capillary movement in baked soils, a plot in the Fresno reclamation experiment tract, well drained by tile, was allowed to bake for two months. The following table shows the changes in alkali content:

*The results of capillary movements in tile-drained soils.*

Depth in feet.	Per cent in soil.								Per cent.	
	Na <sub>2</sub> CO <sub>3</sub> .		NaHCO <sub>3</sub> .		NaCl.		Total.			
	June 15.	Aug. 20.	June 15.	Aug. 20.	June 15.	Aug. 20.	June 15.	Aug. 20.	Gain.	Loss.
1.....	0.090	0.100	0.120	0.132	0.042	0.083	0.252	0.296	17.4	.....
2.....	.081	.081	.120	.066	.067	.083	.268	.230	.....	14.1
3.....	.016	.033	.100	.054	.050	.057	.166	.144	.....	15.2
4.....	None.	.008	.084	.048	.050	.042	.134	.098	.....	27.0
5.....	None.	.025	.108	.048	.117	.033	.225	.106	.....	52.4

It will be noticed that the drainage water removed considerable alkali during the period when the surface soil was dry. An actual gain in alkali was made in the surface foot only. This capillary rise occurred only while the first 2 feet were drying out, and in this manner the alkali from the second foot rose, slightly increasing the amount at the surface. Like observations were made in other checks left during the hot weather. It was noticed that in places containing much alkali a distinct concentration of the salts occurred below the soil mulch, due to evaporation at this point. In other observations it was found that the soil mulch was not effectual in preventing some of the alkali from rising to the surface.

#### THE EFFECT OF ALKALI ON PLANTS.

When caustic alkali carbonates accumulate at the surface of a soil, the root crowns of young plants become seared and the tender rootlets become corroded. The salts which comprise the larger proportion of the alkali at Fresno—carbonates and chlorides—are especially injurious. Kearney and Cameron <sup>a</sup> have found the toxic limit for white lupine seedlings of single salts in solution and for combinations of salts. As a rule the combinations were much less toxic than single salts. For instance, the addition of sodium chloride or sulphate to a solution

<sup>a</sup> Report No. 71, U. S. Dept. Agr.

of magnesium chloride or sulphate, which alone is exceedingly toxic, reduces this toxicity many times. The addition of calcium chloride and usually calcium sulphate (gypsum) to solutions of sodium and magnesium salts greatly reduces the toxicity of the latter. The beneficial effect of gypsum in reducing the toxic influence of the alkali salts was observed at Fresno, for in some cases germination of alfalfa was effected only after the application of gypsum, and in other cases the growth of alfalfa was greatly helped.

The roots of such plants as fruit trees, vines, and alfalfa are provided with a thick protective parenchymatous tissue, which becomes corky on its outer surface and which prevents caustic action upon the growing parts if the concentration of alkali in the soil has been sufficiently reduced. During the growing season great quantities of water are taken up and discharged into the air, while the plant is elaborating material for its nutrition. The alkali salts are osmotically rejected and accumulate about the roots. In the late summer, when the water table is falling, the demand for water by the plant is very great and the roots have a harder and harder struggle to absorb this water from the alkali solution, which constantly increases in concentration. A dangerous quantity of alkali may enter the plant, causing various pathological conditions, such as the blackening of the outer portions of the leaves, yellowing, premature dropping of leaves, and weakening of growth, etc. The soil solution may even become so concentrated that moisture is actually drawn from the roots, collapsing the root cells and causing drought effects where in the absence of alkali sufficient water would be available for proper maintenance of plants. This concentration of alkali causes the yellowing and weakening of ends of branches, rosettes of leaves forming by condensing the internodes of the stem. This last symptom is frequent in the case of apple, pear, apricot, nectarine, and peach trees, though similar symptoms develop from other causes. In the case of alfalfa, this yellowing effect, where it is due to alkali, may be cured by heavy flooding. The yellowing and burning effect of alkali is also noticed in the case of hardy shade trees like the eucalyptus, pepper, and umbrella.

#### CROPS ADAPTED TO ALKALI SOILS.

As the land at Fresno became injured by accumulated salts, certain crops survived, or withstood alkali better than others. Farm practice has selected those best suited to the altered conditions. The following account gives the list of plants grown, with their adaptability to alkali.

With the encroachment of alkali, certain trees showed special adaptability, especially certain shade and ornamental trees. These include all the native willows and cottonwoods and the introduced eucalypts,

elms, poplars, mulberries, and palms. Of these, palms and eucalypts seem to be the most resistant and are usually very thrifty.

Most fruit trees suffer severely from alkali, but the pomegranate, fig, olive, and pear, in the order named, are very resistant to all kinds of alkali. Pomegranates make excellent hedges, even in soils covered with a heavy black-alkali crust. Figs, especially the Mission and Adriatic varieties, thrive in alkali soils showing considerable alkali crusts on the surface. Poor drainage conditions do not appear to affect the growth and productivity of the fig. The olive is also a good tree for alkali soils and produces well where alkali is too strong for vines and alfalfa.

Grapevines are very sensitive, especially to black alkali. The lower limit for injury for total salts containing black alkali in the soil is between 0.12 and 0.15 per cent. Old vines established before alkali has become injurious often withstand considerable quantities where soils are deep and fairly well drained, but young vines are very sensitive. Of the vinifera varieties observed in the Fresno region the Muscat is by far the most sensitive, but all varieties suffer from comparatively small amounts. The Rose of Peru and the Feher Zagos in this section are more resistant to alkali than the other vinifera varieties observed, continuing to produce good crops where the others fail. Some of the American resistant stocks and some of their hybrids, with certain vinifera or European stock, show marked resistance.

Where alkali kills out spots in a vineyard or when a damaged vineyard is uprooted, alfalfa is usually planted. This often does well for a considerable time, especially where it is heavily flooded to drive down alkali accumulations on the surface. Where soils are too heavily charged with alkali to grow good alfalfa, wheat and barley are grown. Barley withstands greater quantities of alkali than any other cereal except, perhaps, rice. Barley produces good crops where orchards, vineyards, and alfalfa are killed. When the alkali becomes too strong for grain crops it is planted to Bermuda grass. Bermuda grass has been found flourishing in 6 per cent of black alkali. It seeds itself over the good soils by means of wind, stock, and canal waters, and by its stoloniferous roots. Its feeding roots have been found 9 feet deep in the soil, thus making it drought resistant. It is exceedingly difficult to get rid of and should never be planted except in hopelessly ruined soils. At the present time hundreds of acres are covered with Bermuda grass and considerable revenue is derived from the dairies supported by this grass.

Some soils containing too much alkali for the successful growth of alfalfa are heavily flooded and later plowed and sown to sorghum and Kafir or Egyptian corn. After a summer of this treatment alfalfa often grows well.

Many attempts have been made to introduce alkali-resistant forage plants in these alkali lands. The most promising was the Australian saltbush (*Atriplex semibaccata*). This plant grows well in black alkali soils and takes up considerable alkali, which is removed from the land when the plant is eaten by stock or cut for hay. It has been quite extensively grown in alkali lands at Fresno and elsewhere in the San Joaquin Valley, but, while the saltbush proves quite resistant to alkali and drought, it does not produce abundantly in the more droughty and worst alkali soils, nor is it palatable to stock when grown on such soils.

#### DEMONSTRATION WORK ON THE TOFT-HANSEN TRACT.

For their experiment in ridding land of alkali the Fresno chamber of commerce had selected a tract of land containing about 20 acres. This was situated about  $4\frac{1}{2}$  miles southwest of Fresno in the section where the first successful raisin vineyard was located, and consisted of the Fresno sandy loam (white-ash land). The land was owned by Messrs. S. M. Toft, N. J. Hansen, and J. M. Wilson. The original plan was to install a 6-inch tile drain 9 feet deep running north along Fig avenue. The drainage water was to be lifted from a sump 12 feet deep into a canal by means of a 6-inch piston pump driven by a wheel supplied with water from the Central canal. Two hundred feet of trenches were dug, but at a depth of 8 feet water and quicksand were encountered and it was found impracticable to continue the work. The Bureau of Soils was then requested to take up the unfinished experiment; and although it was clearly recognized that it would be exceedingly difficult to drain successfully a small narrow tract of porous soil, surrounded by water-logged lands, and with the ground water within less than 1 foot of the surface for months each year, the Bureau, on account of the interest manifested by the farmers of the vicinity, decided to carry to completion the reclamation of the tract already selected. The plan of removing the drainage water from a sump hole by means of a water-wheel pump also appeared objectionable. After due consideration of all these questions the Bureau of Soils entered into a three-year contract with the owners of the land. The owners of the tract, according to the terms of the contract, were to provide a sufficient supply of water for flooding, to level and check the land so that flooding could be carried on, and to maintain an efficient pumping system to remove all the water discharged by the drainage system into the sump. On account of the height of the ground water the installation of the drainage system was postponed until the fall of 1902, when conditions would be more favorable for opening trenches and laying tiles. In November, 1902, a drainage system consisting of a main drain 2,010 feet in length and nine laterals 3,650 feet in length was installed. As the tract was practically

level, fall could only be secured by laying the main and laterals nearer the surface as they receded from the sump. On account of the extreme height to which the ground water rises at certain seasons and of the difficulties previously experienced with hardpan and quicksand it was decided to place the tiles at an average depth of 3 feet. The water table each year rose much higher than this depth and it was feared that the drainage system placed at a greater depth would be swamped by the rush of water from surrounding farms and would prove ineffectual. Six-inch tiles were secured for the mains, but a large number of 3-inch tiles had to be used in the laterals, as the order for 4-inch tiles could not be filled.

In Central canal a water wheel 14 feet in diameter by 8 feet in width composed of 18 blades had already been installed. By means of chain and sprockets a China pump elevator was attached which lifted the water through an inclined, tightly boxed trough.

As soon as the canal began to carry water flooding was commenced. At first the tiles drained nicely, but soon silt and sand washed into them and in places completely clogged them. The question of keeping the tiles free from silt proved very troublesome from the outset. The soils on the tract carry large quantities of micaceous silt which enters the tiles readily with the water. Many hundreds of feet of tiles were in this manner soon filled with silt, making it necessary to dig them up and clean them. At the next flooding this process of silting was repeated. Attempts were made to move the silt by placing silt boxes or manholes at the junction of the laterals with the main and from these openings to force spliced rods through the tiles, but the failure of the China pump to remove the drainage water as fast as it accumulated caused the tiles to become filled with silt in spite of efforts to keep them clean.

Meanwhile the flooding had been kept up and levees had been raised over the lines of drains in an attempt to prevent the water washing silt into them. At the end of the irrigation season an alkali survey showed that the injurious quantities of alkali had been driven down from the upper layers of the soil from all but a few spots, where hardpan closely approached the surface or where the land could not be deeply covered by irrigation water. Summer crops planted after the irrigation season determined to what extent reclamation had progressed. Some alkali soon rose again as a result of the close water table. Crops of alfalfa and grain were successfully grown during the next winter and spring, 1903-4, on the checks more fully reclaimed, producing \$93.75 from 3 acres of alfalfa and \$136 worth of grain hay from 7 acres, making an average of \$23 per acre for the 10 acres in crops. During the season of 1904 the crops already growing were irrigated and the rest of the tract heavily flooded to remove fully the remainder of the alkali. Such success was attained by this work that

in the fall of 1904 the greater part of the tract was sown to alfalfa and a fine stand secured. The appearance of the entire tract was quite promising and commented upon by all who had watched the progress of the experiment. Early in 1905 a bucket pump replaced the China pump, which had proved inefficient in removing the drainage water. This pump, however, never appreciably lowered the water over the tiles and soon became worn and required constant repair and attention.

On account of the height at which the water stood during the hot summer months large quantities of alkali which had been driven into the lower depths of soil by previous flooding again accumulated at the surface. In spite of this and of the inroads of Bermuda grass on the alfalfa, the total crop yield during 1905 was valued at \$235.

The results of the experiment at the close of the irrigating season of 1905 plainly showed that the water table must be lowered to a greater depth to effect the permanent reclamation of the tract. It was evident that while the alkali could be washed from the upper layers of soil it would return to the surface just as soon as conditions again became favorable. In order to experiment further on lowering the ground water it was decided to install a deep and more extensive drainage system. It was realized that at a greater depth more water would be carried by such a drainage system and that a pump of greater capacity would be necessary. A new drainage system following out these ideas was next installed, the work being completed in November, 1905. The plans are shown on the accompanying diagram (fig. 2).

This diagram shows a main drain 2,010 feet long, into which flow nine laterals at right angles. Six laterals are each 500 feet long and three are each 210 feet long. At the intersection of the laterals with the main, silt boxes 6 feet long by  $2\frac{1}{2}$  feet in width and set 18 inches below the level of the tile were installed. Near the water wheel on Central canal, a sump box extending 10 feet below the level of the ground, 5 feet wide and 10 feet long, was constructed to hold the pumping machinery. In order to clean the tiles and avoid their clogging in the future, the plan employed successfully for the past fifteen years on the Sunnyside Vineyard east of Fresno was closely followed. This plan consisted in placing a one-fourth-inch, 7-strand, galvanized steel-wire cable throughout the whole length of the drains, in attaching wire brushes to the ends of the cables, and in pulling the brushes back and forth through the tiles with the aid of small hand windlasses. In this way three or four men can clean about a mile of tile a day under ordinary conditions. Thorough cleaning once or twice a year is sufficient after the soil is once firmly settled over the tiles. The flat steel wire brushes were patterned after those used to clean city sewers, modified to meet tile drain conditions. These brushes

were made of exactly the same diameter as the tiles to be cleaned—4, 6, and 8 inches. To remove sand and silt an additional plug was made, having the wires replaced with iron washers from 1½ to 6 inches in diameter.

At the time the cable was laid the owners of the tract installed a new pump, with a double row of buckets, giving three times the number carried by the original bucket pump. Owing to the great strain, this pump proved inefficient and was soon replaced by a No. 3 horizontal centrifugal pump with a capacity of from 150 to 400 gallons per minute. In order to generate sufficient speed for the pump, the water wheel was geared up until the pump shaft made from 250 to 500 revolutions per minute according as the current in the canal varied. All the machinery was above ground except the pump, which could be quickly detached and lifted out of the sump. The substitution of the centrifugal for the bucket style of pump was completely successful and fully solved the problem of removing the drainage water and incoming silt.

FLOODING VINEYARDS FOR  
ALKALI BURN.

While the demonstration experiment was continuing on the Toft-Hansen tract, the opportunity to try the effect of flooding on grapevines affected with alkali burn was presented, and a careful study was made of the conditions before, during, and after the treatments. Two vineyard plots at some distance from the tract, but still within the influence

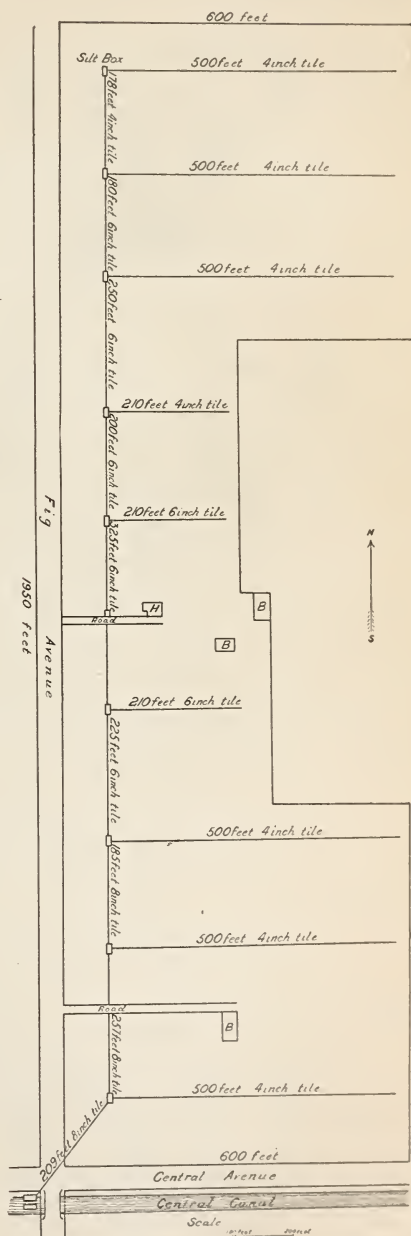


FIG. 2.—Plan of drains, Toft-Hansen tract.

of the drains, were selected for the tests. One vineyard was 20 years old and the other a young vineyard set but two years previously. The vineyards were staked at regular intervals, the stakes numbered, and each foot in the soil column analyzed for alkali before flooding. Analyses of soil at each stake were made as soon as the ground became dry after flooding, several weeks later, and at the end of the summer.

The first flooding in the old vineyard took place early in May. The irrigation was hasty, the water standing to an average depth of 3 or 4 inches only, and remaining over the surface for less than twenty-four hours. The vines showed improvement at once both in crop and in foliage. At the end of the season the vines about stakes Nos. 2 and 3 showed alkali burn, while those about No. 1 were fresh and green. Nos. 2 and 3 were flooded to a maximum depth of 2 or 3 inches only, while No. 1 had a depth of 8 inches over the soil. No. 1 lost more than half its alkali, while the soils about the other two stakes lost but a trace, thereby permitting alkali burn. In spite of this alkali burn, the largest crop in years was produced.

The analyses for alkali in the old vineyard, given in the following table, are those of samples taken from one of the locations marked by stakes. The conditions at this point were typical of the vineyard in general, and it does not seem necessary to multiply the data by presenting the complete records for all the stakes. The analyses show the amount of the salts removed by good irrigation to a fair depth, and the quantity returned to the surface during the summer, the latter being indicated by the difference in the loss shown on May 23 and on August 20, respectively. In some cases there was a gain in the quantity of salts found in the lower part of the 6-foot profile. Such gains, it will be noted, represent the alkali transported from nearer the surface but not carried below a depth of 6 feet. Such cases were, however, both in the old and young vineyard, greatly in the minority.

*Results of flooding old vineyard to relieve conditions of alkali burn.*

Depth in feet.	Na <sub>2</sub> CO <sub>3</sub> in soil.			NaHCO <sub>3</sub> in soil.			NaCl in soil.		
	May 3.	May 21.	Aug. 20.	May 3.	May 21.	Aug. 20.	May 3.	May 21.	Aug. 20.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1.....	0.086	0.033	0.073	0.130	0.084	0.074	0.125	0.025	0.100
2.....	.020	.033	.041	.067	.072	.138	.067	.042	.113
3.....	.008	None.	Tr.	.078	.096	.120	.075	.058	.083
4.....	Tr.	None.	None.	.072	.066	.060	.095	.061	.067
5.....	None.	None.	None.	.066	.054	.066	.067	.050	.053
6.....	None.	None.	None.	.066	.054	.048	.067	.050	.038

*Results of flooding old vineyard to relieve conditions of alkali burn—Continued.*

Depth in feet.	Total salts in soil.			Condition May 21.		Condition Aug. 20.	
	May 3.	May 21.	Aug. 20.	Gain.	Loss.	Gain.	Loss.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1.....	0.341	0.142	0.247	.....	58.4	.....	27.6
2.....	.154	.147	.292	.....	5.9	10.4	.....
3.....	.161	.154	.203	.....	4.4	26.0	.....
4.....	.167	.133	.127	.....	20.4	.....	24.0
5.....	.133	.104	.119	.....	21.9	.....	10.4
6.....	.133	.104	.086	.....	21.9	.....	35.4

While, as stated, the young vineyard treated for alkali had been set out two years previously, the majority of the vines had been replanted at the beginning of the second season. At the beginning of the third season, at which time the experiment was undertaken, the missing spaces had been filled with unrooted grape cuttings, and this third planting covered a large proportion of the 2 acres flooded. At the time of flooding many of the cuttings had commenced to die from alkali burn and the remainder were in bad condition. The water was held as deep as possible over the land, but some parts were so high that the water did not stand more than an inch or two deep at the maximum. The remaining portions improved at once, and the vines assumed a normal bright green and put forth a fine growth. This condition continued throughout the entire season, except on the high parts, where the water during irrigation was shallow. These parts were flooded again in August to offset the alkali drought effect, with great success in restoring the normal green in the leaves. Only a little water was used in August, for fear of sun scald. One week of flooding 6 or 8 inches deep in May did not injure a single vine by scalding.

At the close of the season the vines treated in this experiment were bright green and growing nicely, while the vineyard next to it and only 10 feet from the irrigated vines was denuded of most of its leaves, and none of those remaining was green. Analyses, taken from a typical boring, show the movement of alkali downward and toward the surface in each foot. The vineyard was kept well mulched during the time covered by these records. The remarks explanatory of the conditions in the old vineyard in general apply here.

Nearly all the soil before irrigation at the beginning of May contained sodium carbonate. After flooding, the soils at many of the borings entirely lost their sodium carbonate by conversion into sodium bicarbonate and by leaching. After nearly four months of summer weather much of the land was still free from carbonate, while the rest showed this salt in much smaller quantities than existed at the beginning of the experiment. Those soils covered deepest by

flooding or having the more porous texture most readily lost the carbonates and remained more permanently free from them. Where the carbonates were completely removed, the vines showed the best growth.

When this flooding experiment was commenced, the vineyard was thought to be too far from the Toft-Hansen tract to be affected by the drainage system, but it soon became apparent that the land was well drained, which accounts in a measure for the rapid removal of the alkali. This experiment shows that flooding may be successfully practiced in early summer without injury to growing vines even when flooded for a week at a time.

#### GROUND WATER.

Before canals covered the Fresno plains with water the water table was more than 30 feet below the surface. Those soils near the Kings River were first irrigated and later the lands farther out in the valley. The first waters passed downward into the lower strata of soil, which were laid down in an old lake bed, and which slope downward more rapidly than the surface of the land and are the source of an artesian water supply. In the soils irrigated farther away from the river the water could not escape so rapidly on account of the red hardpan and on account of the substrata. Excessive irrigation soon filled the substrata, then the subsoil, and later the soil to within 2 to 3 feet of the surface, causing great destruction in orchards and vineyards over a large area. Instances are on record of as high as 27 feet of water having been applied to the surface during a single irrigation season.

Subirrigation was also practiced at Fresno, but was abandoned when the water table rose near the surface. Since then many vineyards, orchards, and alfalfa lands have not been irrigated for long periods of years. Where the soils contain no alkali, subirrigation is regarded by many farmers as beneficial rather than injurious. This is true of much of the red hardpan lands where little or no alkali exists.

Over a large part of the Fresno district the ground water now rises to within a few feet of the surface each year and drainage must be resorted to in order to prevent the widespread destruction in orchards and vineyards. It has been thought that leakage from canals was the cause of the rise of the water table, but an examination of the canals showed that they were cemented or puddled by deposits of fine silt from the mountain wash. This silt filters into the porous sandy soils and is packed under a great pressure of water for several months of the year. Only in the case of new canals or laterals is there any considerable leakage. This has been borne out by observations on the height of the water table both near and at some distance from the principal canals, the water table at the canal being at the same height

as several hundred yards distance. These observations show that the condition is due almost entirely to excessive irrigation without proper drainage. Systematic drainage is therefore the only means of permanent relief from the ground-water injury over a large part of this area.

In some cases, especially in the red hardpan lands, drainage has been resorted to in order to save vineyards and orchards from injury due to ground water. Drainage systems on certain ranches have been very profitable and have been in successful operation for many years. The cost of these drainage systems has frequently been covered by increased yield of crops in two years' time.

#### ANNUAL FLUCTUATION OF GROUND WATER.

With the beginning of the irrigation season each year the upper lands fill with water, which moves slowly through the soil with the slope of the land. When the maximum height of ground water is reached many miles of country between Sanger and Ormus become more or less water logged. In the wells near the Toft-Hansen tract <sup>a</sup> it was found that during this period the average rise of water was one-half inch a day until a maximum was reached in May, or later during seasons of late spring snows and rains.

Observations taken on the Toft-Hansen tract of the height of ground water from September, 1905, to October, 1906, are given in the following table:

*Monthly variation of the water table in the vicinity of the Toft-Hansen tract.*

Date.	Depth to water table.	Date.	Depth to water table.
	<i>Inches.</i>		<i>Inches.</i>
1905, September 20.....	66	1906, April 1.....	36
October 20.....	78	May 15.....	36
November 20.....	84	June 15.....	24
December 20.....	102	July 15.....	24
1906, January 3.....	96	August 15.....	30
January 21.....	84	September 15.....	40
February 23.....	50	October 12 <sup>a</sup> .....	68
March 10.....	44		

<sup>a</sup> Canal shut off September 24, 1906.

During the winter months there was not a continuous flow of water in the canal. The irrigating season ordinarily does not begin before the 1st of January, so that there is a period from October to January when the ground water reaches its greatest depth. It is during this period therefore that drainage systems requiring to be laid at a depth of several feet must be installed.

<sup>a</sup> Observations taken during 1903 by the Office of Experiment Stations, and in 1904 by the Bureau of Soils.

A study was made of the daily fall of the water table at the close of the irrigating season of 1906. The records are given in the following table:

*Fall of the water table at the end of the season.*

Date.	Depth to ground water at sump.	Date.	Depth to ground water at sump.
	<i>Inches.</i>		<i>Inches.</i>
September 24 <sup>a</sup> .....	100	October 6.....	65½
September 25 <sup>b</sup> .....	44	October 8.....	66½
September 27.....	50	October 9.....	66½
September 29.....	55	October 11.....	67½
September 30.....	60	October 13.....	68½
October 1.....	62		
October 2.....	63	Average fall for 18 days.....	1.375
October 3.....	64	Average for last 10 days.....	0.425
October 4.....	64½		

<sup>a</sup> Prior to shutting off canal.

<sup>b</sup> Water shut off in canal and pumps stopped.

It will be seen that when the pump stopped the water rose 56 inches in twenty-four hours. Earlier in the season, on account of the saturated condition of the soils, a period of only four to five hours was necessary to raise the ground water to the same level. After the first day the ground water dropped rapidly, but later the fall averaged half an inch a day until the water sank to the depth of the silt boxes.

This fall agrees in rate with the rise of the water table at the beginning of the irrigation season. Elliott <sup>a</sup> also found that the ground water rose at the rate of half an inch a day until the maximum was reached for that season. From this concordance between the rise and fall of the ground water, half an inch a day seems to be the rate of the water movement through these soils under ordinary conditions, while drainage produces a more rapid movement of soil waters.

#### EFFECT OF DRAINAGE ON THE WATER TABLE.

It was found that the drainage system immediately lowered the ground water to the depth of the tile on the Toft-Hansen tract, except where depressions occurred in the hardpan. As the season progressed an increase in the flow of drainage water was noticed. On investigation it was found that cellars to the north and east of the tract had for the first time in many years become dry during the high-water season. Ponds half a mile away that in previous years had remained full until the canal was shut off in the late summer, now either became dry or nearly so.

In order to test this drainage at a distance the behavior of the water in the cellars drained was carefully noted. On stopping the pump, the cellars filled to their old level within twenty-four hours. When the pump was started, within twenty-four hours the cellars again became dry. This was quite noticeable in a cellar on Elm

<sup>a</sup> Report on Drainage Investigations, 1903, Office of Expt. Sta.

avenue, more than three-fourths of a mile away to the northeast and directly in the line of the country slope. Here the drainage was so complete that after the canals stopped running at the end of the irrigating season the land was free from water to a depth of 7 feet, while surrounding lands shut off from it by elevations in the hardpan showed water at 4 feet.

It must not be understood from these statements that water passed through three-fourths of a mile of soil in twenty-four hours. The water in the cellar was actually drained a short distance only, but all the water in the soil between cellar and sump was drained the same distance by this simultaneous water movement.

Conservative estimates at the close of the season placed the number of acres affected by the drainage system on the Toft-Hansen tract at 250. As the tile drains actually covered only 20 acres, it will be seen at once how far-reaching are the effects of drainage in these Fresno soils. The fall in this neighborhood is about 5 feet to the mile in a southwesterly direction. Consequently by securing a rapid passage of water through the soil by means of tile, together with the natural sand channels, the land above the drainage system in the direction of the natural slope may have the water table reduced to a lower level than the land immediately drained. For the same reason, much larger quantities of water must be carried through and away from land nearest the tiles in order to keep it sufficiently drained.

The land lying immediately below the tract in the direction of the fall of the country did not receive much benefit from the drainage beyond a few hundred feet, except as drained water was intercepted in its passage across the tract. This probably amounted to very little, as the land here is flat and the passage of water slow.

To accomplish this amount of drainage, a daily discharge varying from 200,000 gallons at the beginning of the season to 350,000 gallons for the middle and latter part was found to be sufficient.

The experiments on the Toft-Hansen tract, as well as numerous other examples of drainage, showed that the ground water can be kept at sufficient depth over a large number of acres with a comparatively small drainage system. At Selma a ditch constructed to connect ponds and depressions lowered the water table and at the same time carried away large quantities of alkali. In some cases the water table may be lowered over a considerable area by pumping from shallow wells, which should be 8 to 10 feet deep. At that depth water-bearing silt or coarse sand, which conducts water with great rapidity, is usually encountered, thus affecting a considerable area. One objection to this plan of pumping off excess drainage water is that the flow of water will not be sufficient to supply the pumping plant. When supplementary drainage ditches are used in addition to the pump the water is carried from a shallow depth of soil over a large area.

## COMPOSITION OF GROUND WATER.

The following table gives the composition of the drainage water pumped from the tract at Fresno:

*Composition of the drainage water of Toft-Hansen tract.*

Date.	Ca.	Mg.	Na.	K.	SO <sub>4</sub> .	Cl.	HCO <sub>3</sub> .	CO <sub>3</sub> .	Parts per million in solution.
1903.	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	
Mar. 28	8.90	3.77	11.78	2.66	12.23	6.66	54.00	-----	450
Apr. 25	6.91	6.06	7.88	2.18	4.85	8.85	63.27	-----	824
May 2	3.59	4.15	16.35	1.75	2.39	8.95	60.99	1.83	1,251
9	3.57	3.64	20.49	1.58	2.06	9.62	51.82	7.22	1,454
16	3.58	3.76	19.72	1.44	1.88	9.69	54.79	5.14	1,592
23	5.36	4.28	15.47	1.76	3.06	10.73	59.34	-----	1,306
30	2.07	3.47	23.55	2.00	7.01	10.55	40.63	10.57	1,639
June 6	3.01	3.15	22.84	2.35	6.45	11.79	40.50	9.79	1,495
13	3.24	2.96	22.70	2.19	3.91	13.35	43.32	8.29	1,048
20	3.81	3.21	21.82	1.87	2.79	11.78	54.19	-----	1,494
21	3.20	3.38	21.09	2.82	2.63	9.88	56.96	-----	1,062
July 4	3.06	2.27	20.82	2.63	4.98	6.12	57.21	2.97	1,143
11	3.60	1.69	23.04	3.77	6.38	18.09	39.32	3.90	768
1906.									
June 9	2.96	2.70	21.74	1.16	4.69	12.72	53.50	.53	1,109
23	-----	-----	-----	-----	-----	-----	-----	-----	864
July 8	-----	-----	-----	-----	-----	-----	-----	-----	944
21	3.28	2.95	21.74	1.13	3.17	13.60	51.07	3.06	883
Aug. 4	-----	-----	-----	-----	-----	-----	-----	-----	776
18	3.40	2.40	21.76	.62	2.86	12.00	56.96	-----	1,117
Sept. 1	4.39	2.81	19.94	1.01	3.15	13.52	55.18	-----	888
15	3.61	2.58	21.17	.93	2.89	13.12	55.70	-----	968

The irregularities or variations in the analyses of the water for 1903 are due to the intermittent pumping, which was at the same time insufficient to reduce the water table to the level of the tile. With few exceptions the quantities of the various constituents of the soluble salts in these analyses compare closely with those for 1906, when the pump worked well and kept the water down to the tile, but the total salt content differs considerably. The analyses for 1906 show a very uniform proportion for the various constituents, with the exception of the carbonates. No normal carbonates were found at any time in the drainage water of the tract. The remaining slight variations are due in each case to a change in dilution from an increase in the flow of drainage water.

Cameron,<sup>a</sup> in his discussion of "the composition of the drainage waters of some alkali tracts," showed that this unvarying composition would necessarily occur until one of the solid components is entirely removed from the soil by the action of drainage or leaching waters, a relatively small proportion of a component which has entirely passed into the soluble state remaining behind held absorbed by the soil grains. Selective absorption may also play some part, each component passing out at a different rate of speed. The following table of analyses of the drainage water taken from the nine laterals on the tract shows the action of chlorine under leaching.

<sup>a</sup>Jour. Amer. Chem. Soc., Vol. XXVIII, No. 10, Sept., 1906. See also Cameron and Bell, Bul. 33, Bureau of Soils, U. S. Dept. of Agriculture.

*Composition of drainage water from laterals.*

	Parts per 100,000.				Proportion in per cents.	
	Na <sub>2</sub> CO <sub>3</sub> .	NaHCO <sub>3</sub> .	NaCl.	Total.	NaHCO <sub>3</sub> .	NaCl.
June 6, 1906.						
Lateral 1.....	None.	63.60	37.73	104.30	63.9	36.1
2.....	None.	66.73	48.08	114.81	58.1	41.9
3.....	None.	66.93	37.73	104.66	63.5	36.5
4.....	None.	60.45	52.23	122.70	53.7	46.3
5.....	None.	66.73	18.87	85.60	78.0	22.0
6.....	None.	70.87	2.17	73.04	97.1	2.9
7.....	None.	68.81	14.08	82.89	83.1	16.9
8.....	None.	66.93	20.88	87.81	76.3	23.7
9.....	None.	45.87	5.08	50.95	90.1	9.9
July 30, 1906.						
Lateral 1.....	None.	103.47	39.00	142.47	72.6	27.4
2.....	None.	62.14	29.43	91.56	67.9	32.1
3.....	None.	57.97	21.77	78.74	72.3	27.7
4.....	Dry.	Dry.	Dry.	Dry.	Dry.	Dry.
5.....	None.	63.18	15.38	78.56	80.5	19.5
6.....	None.	59.22	1.88	61.10	97.0	3.0
7.....	None.	59.22	16.42	75.64	78.3	21.7
8.....	None.	51.71	14.08	65.79	78.6	21.4
9.....	None.	31.29	1.88	33.17	94.4	5.6

The analyses of samples taken from June 6, after the pumping had been going on for over two months, show a loss in the proportion of chlorine. In case of lateral No. 6 the chlorine had reached a point at which very little was given up. No change was noticed two months later (July 30). Lateral No. 9 also shows a very decreased amount of chlorine, which was reduced nearly one-half to July 30. In this case the chlorine seems not yet to have reached its lowest stage, which would likely occur when a content similar to that for lateral No. 6 was reached.

In almost exact corroboration of this, Colby<sup>a</sup> found in his analyses of the drainage water from the drainage system at Chino, Cal., that the chlorine content calculated as sodium chloride decreased in proportion to the remaining salts from one-tenth to one one-hundredth of the total salt content in the drainage water. The period covered was four months, and the length of tile 600 feet, very nearly the same length as the laterals from which the observations were taken at Fresno.

These laterals (Nos. 6 and 9) discharged considerably more water than the remainder. The land about them was more nearly free from alkali, and thus had given up its chlorine, none remaining in the solid state. This change in the proportion of components is what might be predicted when one of them no longer remains as a solid in the soil. Similar changes in the drainage water from the whole tract can not be expected until all the surrounding lands have been washed to the same extent as the soils about laterals No. 6 and No. 9.

The concentration of the drainage water at Fresno given in the tables in parts per million varies according to the volume of water

<sup>a</sup> Calif. Expt. Sta. Rept., 1901-1903

passing through the soil. At the end of the season, while the water was running very slowly in the drains and canal, samples from each lateral were taken at the silt boxes, followed several days later by similar samples taken when the water table had dropped below the tiles. The analyses are as follows:

*Alkali in drainage from laterals when irrigation had ceased and water was running slowly in the drains.*

[Parts per million.]

Date.	Lateral No. 1.	Lateral No. 2.	Lateral No. 3.	Lateral No. 4.	Lateral No. 5.	Lateral No. 6.	Lateral No. 7.	Lateral No. 8.	Lateral No. 9.	Sump.
Sept. 24....	92.4	74.8	74.0	82.0	71.6	72.0	71.2	76.4	10.4	.....
Oct. 1.....	104.0	108.8	85.6	88.8	117.2	123.6	117.6	.....	36.8	74.0

From these results it is seen that the concentration of the salts increases as the water table falls. This is undoubtedly due to the retention of alkali by the soil, which prevents it passing down as fast as the water.

#### USE OF GROUND WATER FOR IRRIGATION.

The flow of drainage water pumped from the tract was sufficient in quantity to irrigate from 1 to 2 acres daily, but the composition of the salts in this water was such as to preclude its use for irrigation on the white-ash soils. The average of total alkali in solution in the drainage water from the tract for the season was about 100 parts of alkali per 100,000 parts of water. In several other drainage tracts in the Fresno region where drainage has been well established, the alkali in solution ranged from 45 parts per 100,000 to as low as 27 parts per 100,000, the amount of soluble salts usually present in the surface wells of the region. It has frequently been noticed that an increase in the flow of water from drains when flooding is practiced increases correspondingly the alkali content in the drainage water. When no irrigation is practiced on the drainage lands or in the immediate vicinity, the alkali in solution in the drainage waters falls to a comparatively small quantity, at which it remains quite constant. This quantity of salts in solution, when drainage has become efficient and steady, is usually so insignificant that no damage to crops need be feared from its use for irrigation on any of the alkali-free soils at Fresno. Such water may even be effectively used in reclaiming alkali lands from an excess of salts.

The alkali at Fresno is composed mainly of the bicarbonate and chloride of sodium, and a drainage water containing such a combination in quantities greater than 60 or 70 parts per 100,000 should not be applied as irrigation water to any except a very porous and well-drained soil. When such water passes slowly through the soil or remains stationary the alkali is either retained to a considerable extent or partly returns to the soil surface.

A tile filled with alkali-free soil, placed on end in a pan containing 2 inches of this drainage water, within two and one-half days had started a black alkali crust on the surface of the soil 12 inches above the water. A similarly placed soil column treated with pure canal water remained saturated but 4 inches above the water line after three weeks, while the soil treated with drainage water was completely saturated after a few hours, causing a continuous passage of alkali to the soil surface, and increasing the alkali crust until the experiment was stopped. The use of this drainage water on these fields would probably act in a similar manner and in a short time would damage them badly.

Ponds of ground water filling depressions within the body of white-ash lands are usually heavily charged with alkali, and can not with safety be used as a source of irrigation water. Similar ponds in the Fresno sand, a very loose, deep soil, are frequently found near irrigated lands. Around Selma these ponds once contained considerable quantities of alkali, but by cutting channels between them,<sup>a</sup> the passage of the drainage water through the soil was so greatly increased that their alkali content decreased, and the water can now be safely used for irrigation. Ponds not artificially drained often occur in the Fresno sand. These in many cases are partially drained by underground channels in old stream beds, the movement being sufficient to reduce the alkali content below the danger point. The water in such ponds is often successfully used in irrigation. Ponds of this class containing bicarbonates and chlorides up to 40 parts per 100,000 have been used without injury to irrigate vineyards, peach orchards, and alfalfa on the Fresno sand. With this type of soil, however, the ground water is more than 10 feet below the surface at all seasons. Pumping plants on such soil may be operated without danger of damaging the land from the accumulation of alkali.

#### EFFECT OF DRAINAGE WATER UPON CANAL WATER.

Some anxiety was felt by irrigators using water below the point on the canal where the drainage water from the tract was added. In order definitely to determine the change in salt content in the canal due to an addition of drainage water samples of the canal water were taken above the inflow of drainage and one-fourth mile below—a point where the waters had become thoroughly mixed. The canal water contained 35 parts per million of soluble salts. After the drainage water had been added to it, the salt content increased to 40 parts per million. The soluble material in both cases was about one-half dissolved silica and the remainder alkali

---

<sup>a</sup> Circular No. 50, Office of Expt. Sta., U. S. Dept. of Agr.

salts. The increase of alkali due to the addition of drainage water is, therefore, so slight that a quantity of such water many times in excess of that now discharged from the drainage system into the canal would be required to render the water of the canal, unfit for irrigation.

As drainage is extended and continued the alkali content of drainage water will become much less, and undoubtedly this water will in time become fit for use in irrigation without an admixture of the pure canal water. The natural drainage water passing downward through the soil and away through natural channels, relieved of the excessive surface and soil water, will carry away much of the alkali washed out of the surface of the soil during the process of irrigation.

During the process of flooding, a certain proportion of soluble inorganic salts known as plant foods was removed from the soil by the drainage water. There was some fear expressed by farmers and others <sup>a</sup> that the amount of plant food removed would seriously impair the fertility of the soil. The canal water used for irrigating the tract and the drainage water removed from it were analyzed for potassium and phosphoric acid to determine the amount of these plant food constituents:

*Soluble salts in parts per million.*

Sample.	Constituent.			Total.
	P <sub>2</sub> O <sub>5</sub> .	K.	SiO <sub>2</sub> .	
Irrigation water, Fresno, Cal. ....	4	3	17	35
Drainage water, Fresno, Cal. ....	18	101	20	888
Drainage water, Chino, Cal. <sup>a</sup> .....	17	6	25	837

<sup>a</sup> Analyses made by Prof. Geo. E. Colby, Cal. Expt. Sta. Rept. 1901-3.

The drainage water from drain at Chino and the drainage from the Toft-Hansen tract carried nearly identical quantities of phosphoric acid. The proportion of potassium was much greater in the latter, but not high enough to cause any uneasiness, because in alkali soils this salt is usually present in excess of the amount generally required for plant growth.

That the concentration for phosphoric acid is nearly constant at a low percentage may have been expected from results in a former publication of this Bureau.<sup>b</sup> This dilute concentration is kept constant by the slight solubility of phosphates,<sup>c</sup> and by the absorptive properties of the soil. There appears, therefore, to be little danger that overmuch plant food will be removed during the process of alkali reclamation.

<sup>a</sup> Cal. Expt. Sta. Rept. 1901-3, pp. 65 and 83.

<sup>b</sup> Whitney and Cameron, Bul. No. 22, Bureau of Soils, U. S. Dept. of Agr.

<sup>c</sup> See Schreiner and Failyer, Bul. No. 32, Bureau of Soils, U. S. Dept. of Agr.

## OTHER METHODS OF ALKALI RECLAMATION PRACTICED AT FRESNO.

Besides reclamation by underdrainage and flooding, other methods have been attempted at Fresno. Some of these are as follows: Flushing off the top or surface crust of alkali; breaking holes through the hardpan; working in manure by frequent tillage; tilling constantly during the summer to prevent the rise of alkali by evaporation and capillary movement; applying gypsum as antidote to black alkali; cultivation of alkali resistant plants; and flooding in checks without underdrainage.

## USE OF GYPSUM.

Directions have been given by Hilgard<sup>a</sup> for the use of gypsum, to correct the caustic black alkali by changing it to neutral sodium sulphate, which is much less toxic to plants. However, it was noticed that in one spot at Fresno where gypsum had been used much black alkali persisted, even though large quantities of gypsum were added. Quantities of gypsum placed about fruit trees when planted did not prevent them from being killed by black alkali, although plenty of irrigation water was used. It was observed, however, that land treated with gypsum soon shows improved physical condition and will allow the more ready percolation of water. Improved conditions in soils where black alkali continues to exist is due, partly at least, to flocculation of the soil particles caused by the gypsum.

There are many reasons why gypsum fails to effect a permanent reclamation of the black alkali. Among these are its slight solubility, insufficient amounts of gypsum and water used, the reverse reaction to form sodium carbonate, the breaking down of gypsum by living organisms in the soil, and the continued formation of sodium carbonate by reaction of common salt on the hardpan below.

The following table taken from a report by Lapham and Heileman<sup>b</sup> gives the quantity of gypsum necessary to neutralize black alkali in a foot depth of soil by the chemical reaction changing it into sodium sulphate:

*Amount of gypsum necessary to correct black alkali.*

Per cent of sodium carbonate in soil.	Tons of gypsum necessary to neutralize an acre to a depth of 1 foot. <sup>a</sup>	Per cent of sodium carbonate in soil.	Tons of gypsum necessary to neutralize an acre to a depth of 1 foot. <sup>a</sup>
0.01	0.3	0.20	5.7
.05	1.4	.30	8.5
.10	2.8	.40	11.2

<sup>a</sup> The weight of 1 acre-foot of soil is taken as 3,500,000 pounds.

The average purity of the commercial gypsum used is about 85 per cent, which makes it necessary to add 15 per cent more gypsum than

<sup>a</sup> Bul. No. 128, Col. Expt. Sta.    <sup>b</sup> Soil Survey of Hanford Area, California, 1901.

indicated by the above table. According to Means<sup>a</sup> the amount of normal carbonate in the affected district varies from 0.10 to 0.20 per cent. As the bicarbonate is about equal in quantity to the normal carbonate and readily reverts to it enough gypsum must be added in addition to overcome the bicarbonate. With gypsum at \$5 per ton it would therefore require from \$112 to \$228 per acre to entirely convert the black alkali contained in the soil to a depth of 4 feet. Furthermore, it is also well known that gypsum is required in considerable excess over the amount indicated by the theoretical chemical reaction.

Loughridge<sup>b</sup> found that twice the equivalent quantity of gypsum was necessary to cause a satisfactory decrease in the amount of black alkali, and that the reaction took place in less time than three days. In many places where gypsum was applied it was found after three years only partially dissolved by irrigation or rain. It would therefore be necessary to increase the amount of gypsum greatly above the quantity indicated above.

The amount of water<sup>c</sup> required to render the greater portion of the gypsum soluble to a considerable extent is far in excess of that used in the usual practice of irrigation. The large quantities of water used to reclaim black alkali lands would render the gypsum entirely soluble and this would greatly hasten reclamation by converting the more resistant sodium carbonate to the easily leached sodium sulphate.

Poorly drained soils are filled with quantities of carbon dioxide, which renders calcium carbonate in the soil soluble as calcium bicarbonate. Calcium bicarbonate reacts with sodium chloride to form sodium bicarbonate, which on loss of carbon dioxide forms the normal sodium carbonate. This process replaces the sodium carbonate removed from soil by the reaction with gypsum. The more rapid and complete the action of gypsum on black alkali the more rapid is the reaction of sodium chloride and calcium bicarbonate to supply the depleted sodium carbonate.

Bacteria tend to destroy the effect of gypsum by breaking it down with the formation of hydrogen sulphide, which escapes into the air.<sup>d</sup> In water-logged or swampy lands in poorly drained alkali areas gypsum is attacked by the thio-bacteria, *Beggiatoria alba*.<sup>e</sup>

This condition, resulting in the breaking down of the sulphates, was noticed while draining the tract. Before the tiles began to run properly and the water remained stagnant in the soil, a strong odor of hydrogen sulphide was detected in the sump and silt boxes. As soon

---

<sup>a</sup> Soil Survey Around Fresno, Cal., 1900.

<sup>b</sup> California Expt. Sta. Report, 1895-96, p. 40.

<sup>c</sup> For solubility of gypsum in water and solutions see Bul. No. 33, Bureau of Soils.

<sup>d</sup> Schreiner and Failyer, Bul. No. 31, p. 51, Bureau of Soils.

<sup>e</sup> Ibid.

as the drains began to run properly, this odor entirely disappeared and did not return.

Finally, it must be remembered that, while the toxicity of the alkali is greatly reduced, the quantity is actually increased by the resulting sodium sulphate.

#### CONSTANT TILLAGE.

In the vineyards and orchards at Fresno constant tillage is practiced during the growing season to prevent the rise of alkali which has been washed down during the winter by rain. Vines and trees are greatly invigorated by this extra culture, which enables them better to withstand the inroads of alkali. This practice, however, will not prevent the ultimate ruin of the orchards where the water table is close to the surface.

#### INCORPORATING BARNYARD MANURE.

Plowing quantities of barnyard manure into alkali land has been found greatly to improve heavy soils which contain a small amount of injurious alkali. This method coupled with frequent cultivation appears to have overcome entirely the effect of alkali. This is due not to the removal of alkali, which is present in even greater amounts by addition of that contained in the manure, but to the scattering of the alkali evenly through the soil. At the same time the capillary movement, which would soon concentrate the alkali at the surface, is checked. Moisture is likewise conserved by the extra tilth and added organic matter. This is a favorite and successful method with Italian and Chinese gardeners.

#### BLASTING HARDPAN.

Breaking holes through the hardpan to the underlying water-carrying sands by digging or dynamiting has given poor results for the outlay of time and money. The water table is too close to the surface and is usually above the hardpan during the growing season, thus preventing the drainage of alkali water down into the lower strata. An attempt was made to reclaim an alkali spot on the Toft-Hansen tract by blasting the hardpan during early summer, but it proved a failure, for the hardpan was so tough that no cracking occurred and only small holes were opened, which soon filled, and becoming puddled were almost as impervious as before. Blasting during the dry season of the year would probably have shattered the hardpan to a greater extent.

#### SURFACE FLUSHING.

Flushing, or washing off the surface by running water, is usually efficient in removing most of the surface alkali, but it must be repeated continually. Fields are often greatly improved by this method, and it is also a most valuable adjunct in reclamation by underdrainage, removing quickly most of the crust or surface salts. On a portion of

the Toft-Hansen tract where hardpan existed within 2 feet of the surface flushing was practiced by passing the water over the land into the drainage system. Every two or three days this surface flushing was repeated. At the end of five or six weeks half of the alkali was removed. The following table shows the rate at which alkali went into solution:

*Rate of solution of alkali near the surface of the soil.*

[Parts per 100,000.]

Hours.	Na <sub>2</sub> CO <sub>3</sub> .	NaHCO <sub>3</sub> .	NaCl.	Total.	Notes.
0	0	1.85	1.74	3.59	Canal water June 15.
$\frac{1}{2}$	-----	10.40	4.16	14.56	
$\frac{3}{4}$	-----	13.75	5.80	19.55	
20	-----	20.86	7.54	28.40	Drained and evaporated to one-third. Evaporated almost to dryness.
48	Trace.	23.36	9.28	32.64	
96	7.56	17.48	9.28	34.32	

The analyses in this table show that practically all the alkali at the surface of the soil goes into solution in two days. A great proportion of it was found in solution after three hours. This shows that a period of time varying from three to twenty-four hours would be sufficient to dissolve the greater part of the surface alkali, and that it would even be practicable to inclose lands containing crusts of alkali on the surface of the soil in large checks and keep a continual stream of water passing over it until the concentrated alkali near the surface was largely removed. Flushing the surface as an aid in cleaning lands from alkali can be successfully used only at the beginning of the flooding.

#### FLOODING WITHOUT UNDERDRAINAGE.

Flooding land in checks to wash down alkali is the oldest method and the one most often practiced in the reclamation of alkali lands. It has been used successfully in many places in the San Joaquin Valley, where the soil is well drained and free from impervious layers of hardpan. At Bakersfield many bad alkali tracts have been successfully and permanently reclaimed by this method. Most of this land is a loose sandy loam or sand for the first 2 or 3 feet, which enables the water to percolate freely. Water 1 foot deep is held over this soil during the spring or irrigating season until May or June. The land is then planted to Egyptian corn, the shade of which retards the capillary rise of alkali. During the next fall or following spring the land is seeded to alfalfa and given as heavy flooding as possible at the usual time for irrigation.

The following table by Loughridge<sup>a</sup> gives the amounts of alkali before and after flooding on an alkali spot near Bakersfield:

*Quantity of alkali in soil before and after flooding.*

	Per cent Na <sub>2</sub> SO <sub>4</sub> in soil.	Per cent Na <sub>2</sub> CO <sub>3</sub> in soil.	Per cent NaCl in soil.	Total salts in soil.	Per cent total leached out.
Before flooding.....	0.385	0.004	1.127	1.580	.....
After flooding and with good stand of alfalfa.....	.092	None.	.007	.119	93.7

No hardpan existed in this soil, and the ground water fluctuated between 10 and 16 feet below the surface of the soil.

At Fresno this method has been tried in many places. Near the Toft-Hansen tract a field was successfully reclaimed from alkali in this manner and produced good barley and alfalfa. In changing owners the policy of repeated deep flooding was discontinued, the result being that in the course of a season or two the alkali came to the surface and ruined the land. The success of flooding alone, i. e., without artificial underdrainage, at Fresno depends largely upon the variations of the water table.

#### RECOMMENDATIONS FOR RECLAIMING LANDS AT FRESNO.

From the experience of the Bureau of Soils in reclaiming the Toft-Hansen tract, the following recommendations are given for those contemplating similar work:

As hardpan of irregular contour is present at varying depths in most Fresno alkali soils, the first work should be to map the depth of this formation. This is readily done by the use of a 6-foot soil auger. Hardpan below 6 feet is not dangerous. This boring gives the depth of the soil and its texture and shows where the lines of tile may be placed to avoid digging through excessive depth of hardpan. The channels and depressions in the hardpan can thus be taken advantage of, as well as the natural fall of the country drainage, and the distance between the tile mains and laterals can be determined to the best advantage. Main lines of tile one-fourth mile apart appear to be sufficient in the Fresno sand or the Fresno sandy loam, when supplemented by additional laterals to spots retaining alkali in excessive amounts. Drainage flows from the entire district have been discussed by Elliott.<sup>b</sup>

In planning a small drainage system the most serious concern is an outlet for the drainage water. At Fresno there are two possible methods for carrying away drainage water—gravity and pumping.

<sup>a</sup> California Expt. Sta. Report.

<sup>b</sup> Office of Expt. Sta., U. S. Dept. of Agr., Drainage Investigations, 1903.

As the fall of the country is 5 feet to the mile or less, in order to secure a gravity outlet 7 or 8 feet deep it would be necessary that the ditch be dug into Fresno slough 15 miles from the area affected. Power for pumping may be obtained by using gasoline, electricity, or water. The latter power is afforded by the large canals of the district, and was used in the Toft-Hansen tract experiment and by several other drained farms at Fresno. A water wheel of sufficient power to lift the drainage water from 250 to 300 acres costs about \$250. Aside from accidents, the cost of running the water wheel pump or lift is low. The gasoline engine is, of course, more expensive, but can be operated at any time. The electric power pump is far easier to manipulate and requires little care. Electric power promises to be cheap and available for this work in the near future.

The silting of tiles has proved serious, not only in the arid lands of the United States, but also in India<sup>a</sup> and elsewhere. Tiles should be fitted together as closely as possible, for otherwise sufficient silt enters to fill them, especially in micaceous sandy and silty loams. In heavy loams, cohesive sandy loams, clays, and adobes silting does not occur to any appreciable extent. Attempts to prevent silt from entering the tiles by placing hay or tarred paper over the joints have not been effective. The manner in which this difficulty has been overcome on the Toft-Hansen tract has already been described.

The roots of fig, elm, eucalyptus, willow, poplar, cottonwood, and maple trees may be cut out of tiles quite readily with the steel wire brushes, which also have been described in this paper, if the trees are not closer than 30 feet. Vines may be planted much nearer, and alfalfa does not enter unless the tiles already contain large quantities of silt.

The cost of installing a drainage system at Fresno comes under three heads, namely, cost of tiles, expense of laying them in the ground, and expense of providing an outlet for the drainage water. No attempt will be made to give the cost of a drainage outlet, for this item varies for each farm. The cost of the first item, tiles, varies from year to year, but as there is now a local supply large orders of tiles should be obtainable at comparatively low prices. The prevailing prices on small lots during 1905 were for 4-inch, \$32; for 6-inch \$72, and for 8-inch \$120 per thousand feet f. o. b. at Fresno. The second item of expense—laying the tiles—was 5 cents per linear foot for tiles placed in the ground at a depth varying from 5 to 7 feet.<sup>b</sup> Along the

---

<sup>a</sup> Annual Report, Imp. Dept. of Agr., India, 1904.

<sup>b</sup> For a complete description of the methods of surveying drains and laying the tiles in place, see Drainage of Farm Lands, Farmers' Bulletin No. 187, U. S. Dept. of Agr., and Engineering and Drainage, both by C. G. Elliott. These publications give the simplest and most effective methods in use by farmers.

lines of mains and along laterals of great length boxes should be placed 18 inches below the tiles at intervals of 300 feet to serve as silt basins. If redwood lumber is used in making them, it should be at least  $1\frac{1}{2}$  inches thick, as thinner boards warp and allow earth to enter between the cracks. A good box for this purpose is about 6 feet long and  $2\frac{1}{2}$  feet wide, inclosed with a close-fitting cover. In the drains between these boxes a cable should be laid, with a windlass at each end to pull the cleaning brushes back and forth. Such windlasses cost about \$7.50 each, the wire brushes \$6 each, and the 7-strand quarter-inch galvanized steel wire cable about \$8 per 1,000 feet.

The cost of leveling and checking ranges between \$5 and \$30 an acre. On many farms in the alkali district southwest of Fresno the land has already been leveled and ditched for irrigation by flooding. The cost of reclaiming these lands may be estimated to be between \$10 and \$30 an acre, not including the expense of labor in applying the water and cleaning the tiles.

The best time to flood is during the winter when evaporation and the capillary rise of alkali are slight. Evaporation during the winter months decreases to one-fifth of that during the summer months. The ground water at this time is also very low, enabling the water carrying the alkali to pass deeply into the soil. This flooding may be done by pumping water on the land from wells before the canals begin to run. Afterwards canal water can be applied more cheaply.

#### DEPTH OF FLOOD WATER.

In order to remove sodium carbonate a good depth of water over the soil is necessary. A depth of water from 1 to 4 inches is not sufficient on the white-ash lands to convert carbonates completely or to drive down alkali, but may be sufficient on sandy soils.

For several reasons a much larger quantity of water than is necessary to dissolve the salts must be used to remove alkali successfully. Water passes downward through the larger spaces, leaving almost undisturbed the alkali in the more compact soils. Each soil grain holds absorbed on its surface a part of the dissolved salts. Most fields are of uneven texture and allow water to percolate more rapidly in some places than in others.

The rate of passage of alkali salt under various depths of water is given in the following table:

*Rate of leaching out alkali from soil by flooding.*

Stake number.	Depth.	Na <sub>2</sub> CO <sub>3</sub> in soil.		NaHCO <sub>3</sub> in soil.		NaCl in soil.		Total salt in soil.		Maximum depth of water over soil.	Duration of flooding.	Proportion leached out.	
		Before flooding.	After flooding.	Before flooding.	After flooding.	Before flooding.	After flooding.	Before flooding.	After flooding.			Gain.	Loss.
	<i>Feet.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>Inches.</i>	<i>Days.</i>	<i>P. ct.</i>	<i>P. ct.</i>
I	1	0.293	0.019	0.048	0.067	0.125	0.020	0.466	0.106	3	35	.....	67.3
	2	.090	.024	.066	.072	.067	.033	.223	.129			.....	42.2
	3	.090	.016	.072	.084	.092	.033	.254	.133			.....	47.6
II	1	.291	.106	.108	.084	.609	.033	1.008	.223	2	35	.....	77.8
	2	.098	.098	.096	.078	.092	.042	.286	.218			.....	23.8
	3	.098	.089	.096	.060	.092	.058	.286	.207			.....	47.2
III	1	.293	.057	.126	.084	.701	.033	1.120	.174	3	35	.....	84.5
	2	.065	.049	.088	.060	.133	.042	.286	.151			.....	47.2
	3	.093	.057	.004	.072	.100	.100	.197	.229			16.2	.....
IV	1	.163	.065	.114	.108	.134	.033	.411	.206	2	28	.....	49.9
	2	.098	.054	.018	.065	.159	.192	.275	.311			13.0	.....
	2½	.098	Trace.	.018	.096	.159	.200	.275	.296			7.6	.....
V	1	.198	None.	.048	.050	.083	.042	.229	.092	10	35	.....	59.9
	2	.090	None.	.096	.054	.042	.038	.228	.092			.....	59.7
	3	.106	None.	.102	.048	.058	.033	.266	.081			.....	69.6
VI	1	.196	.015	.048	.097	.451	.134	.695	.246	4	21	.....	66.2
	2	.049	.065	.120	.030	.033	.167	.185	.218			18.2	.....
	1	.098	None.	.048	.036	.083	.027	.229	.063			.....	27.5
VII	2	.090	None.	.096	.048	.042	.026	.228	.074	12	42	.....	68.5
	3	.106	None.	.102	.048	.058	.026	.226	.074			.....	.....
	1	.416	.008	.180	.090	.157	.021	.755	.119			.....	84.3
VIII	2	.130	.016	.228	.066	.083	.033	.441	.115	4	28	.....	74.0
	3	.065	.033	.108	.078	.058	.033	.231	.144			.....	37.7
	4	.033	.033	.074	.132	.030	.065	.157	.230			46.5	.....

It will be seen from the above table that where the maximum depth of standing water was close to 10 or 12 inches the total alkali content was reduced below 0.1 per cent and the sodium carbonate entirely converted into bicarbonate. Where this depth of water was used no carbonate again appeared even after two months' summer exposure.

Where a good depth of water was held continually over the soil, five or six weeks' time was sufficient to remove the alkali below the danger limit. Where the soil was heavier in texture more time and a greater depth of water secured the same results. It is not at present advisable to attempt to reclaim lands where hardpan approaches close to the surface, for the depth of soil is too shallow for trees, vines, or alfalfa.

When flooding is practiced in the neighborhood of a dwelling, fresh-water algæ often accumulate, causing offensive odors and unsightly green scum. On the tract at Fresno this was overcome within four or five hours by placing bluestone (copper sulphate) in the water as it ran into the checks of standing water. One part of bluestone (copper sulphate) to 100,000 parts of water is sufficient to secure these results, and the cost is slight.<sup>a</sup>

Evaporation losses are considerable, especially during summer flooding; the daily evaporation on the tract during the month of June was found to be 0.285 inch, making a total of 8.55 inches for

<sup>a</sup> Bul. No. 64, Bureau of Plant Industry, U. S. Dept. of Agr.

the month. The monthly evaporation in the arid parts of California varies from 5 to 9 inches, according to studies made by Lee<sup>a</sup> and Fortier.<sup>b</sup>

Flooding for one season will usually be found sufficient to reclaim all except the most strongly impregnated alkali soils. Occasional deep flooding in succeeding years will keep them free from injurious quantities of alkali.

#### FLOODING VINEYARDS IN ALKALI SOILS.

Where established vineyards are affected with injurious quantities of alkali, flooding to a depth of 1 foot may be continued without injury from December to March, when the vines are ready to sprout. Flooding in vineyards may be practiced during hot weather if care be exercised to prevent sun scald. Alfalfa and trees are more easily injured by standing water than are vines.

In order to determine when the alkali content is reduced below the danger point for vines, it is necessary either to make chemical analyses or to test the soil by practical observation. The following field method may be quite definitely relied upon in the white-ash soils in the vicinity of Fresno to determine the limit below which vines are free from alkali injury: Dig a trench 3 feet deep, 18 inches wide, and 10 feet long from west to east. Allow the sun to shine into it for three or four days. If a dense black discoloration characteristic of black alkali and thickly interspersed with salt crystals plainly appears on the sun-exposed north side of the trench, there is still too much alkali in the soil. If, however, only a brown irregular discoloration and few crystals of salts appear interspersed with streaks of natural-colored soil, the land is free enough for alfalfa and grain; but if no discoloration except that natural to damp soil full of organic matter be present, then vines or any other sensitive plants, such as sweet potatoes, peanuts, etc., may be planted with entire safety. Instead of the cemented and puddled condition the reclaimed soils become loamy and friable.

#### SUMMARY.

In summing up the results obtained by the alkali reclamation experiments of the Bureau of Soils on the Toft-Hansen tract at Fresno, the attention of those owning farms ruined by alkali is again drawn to previous statements of the Bureau of Soils, advising under-drainage and flooding as a remedy for the alkali soil.<sup>c</sup> This method of treating alkali lands has proved a sure and efficient remedy at a cost well within the means of ordinary farmers and but a fraction of the value of the land. A great deal of valuable experience has been gained and is now available to those reclaiming alkali lands.

<sup>a</sup> Geology and Water Resources of Owens Valley, California. Water-Supply and Irrigation Paper No. 181, U. S. Geol. Survey.

<sup>b</sup> Circular No. 59, Office of Expt. Sta., U. S. Dept. of Agr.

<sup>c</sup> Survey Around Fresno, 1900, Bureau of Soils, U. S. Dept. of Agr.

It has been found that alkali can be washed out of these white-ash soils, where no hardpan occurs close to the surface, during one irrigating season. It should then be fit to produce paying crops.

The alkali at Fresno in the white-ash soils consists mainly of black alkali. To remove this alkali rapidly and effectively, it has been found necessary to hold water continually for several months over the soil at a depth of about 1 foot. When this is done, black alkali need not be feared.

The amount of tiling necessary to drain these alkali lands for reclamation has been determined to be far less than formerly thought necessary. Natural stream channels and the great porosity of these soils made it possible to place drains several hundred feet apart, thus materially reducing the cost of reclamation.

Efficient drainage systems, together with pumps of small capacity, have been found to remove easily and permanently a sufficient quantity of ground water to keep the water table below the danger limit throughout the irrigating season. These pumps may be readily driven by power furnished by water wheels in the canals. Cheap electricity also soon promises to be available for this purpose where water power is not to be had.

When installing drainage systems, a competent engineer should be employed in order that the drains may be correctly laid on a proper and uniform grade. A contour survey of the surface of the land, together with one of the hardpan, is necessary to avoid the heavy cost of digging through hardpan and at the same time to secure the best drainage.

In placing the tiles in the trench great care should be taken to crowd them closely together to exclude silt and sand. Silting is a serious problem in many alkali soils, but may be overcome readily by placing cables in the drains and drawing brushes through them.

The time necessary to drive alkali out of the freer soils by continuous deep flooding may be as short as six weeks. Heavier soils require more time, but usually not more water.

The practical trench test, to determine when the alkali has been sufficiently removed and when flooding should cease, should be used. A grain crop should follow during the next winter season. Any spots showing alkali can then be readily detected and treated in the following spring and summer.

With the experience gained by the Bureau of Soils as a guide no insurmountable difficulty in freeing land from alkali should be encountered by farmers. The success attained in draining individual farms at the Toft-Hansen tract and other places clearly demonstrates that such drainage is a permanent and financial success. That such individual work will in time solve the problem of alkali reclamation seems highly probable.

## APPENDIX.

### PLANTS USED AS ALKALI LAND INDICATORS.

The following list of plants more or less resistant to alkali, with a discussion of their relation to alkali conditions in the soil in the Fresno district, is given to assist farmers and others interested in determining the conditions in any given case. In other Western States, and even in other parts of California, the resistance of the same plants may be quite different. In the absence of exact information, such as that afforded by chemical analyses, the value of plants as indicators of alkali is unquestioned. Thus on lands which have not yet been irrigated and planted to crops there are found growing many native plants which thrive best under certain conditions of alkali and in soils of certain depth and texture. While these plants are not always infallible indicators of these conditions, they may in the majority of instances correctly guide the farmer in selecting or rejecting new or hitherto undeveloped lands. In this manner serious mistakes and waste of capital may often be averted.

For identification of alkali lands in the field the following native plants are often successfully used:

Saltwort or inkweed (*Suaeda* sp.).  
Kern County greasewood (*Allenrolfea occidentalis*).  
Saltbush (*Atriplex* spp.).  
Alkali heath (*Frankenia grandiflora campestris*).  
Little rabbit brush (*Bigelovia veneta*).  
Alkali weed (*Centromedia pungens*).  
Arrow or irrigation weed (*Pluchea sericea*).  
Salt grass (*Distichlis spicata*).  
Foxtail or barley grass (*Hordeum murinum*).  
Slender water or alkali grass (*Leptochloa imbricata*).

In discussing these plants the depth and texture of the soil upon which they grow, the amount and kind of alkali (black or white) tolerated by them, and the possibilities for drainage and alkali reclamation are given. The three different grades of alkali—lower, medium or moderate, and heavier—are represented by 0.10 to 0.30, 0.30 to 0.50, and above 0.50 per cent in the soil.

Inkweed, or salt bush, is a perennial shrub with a small, fleshy, stemlike leaf. Each winter the plant dies down close to the ground, leaving behind a dark-colored brush. This plant grows only in badly alkaline soils, usually with high black alkali content and with a heavy sandy loam or clay loam texture. No crop has been found growing on the land covered by this plant. The soil usually occupies a depression in which alkali has accumulated and puddled the soil, holding rain or irrigation water above it until evaporated. Where the inkweed grows on elevated soils, there has usually been found hardpan close to the surface. Such land has not been profitably reclaimed from alkali.

Kern greasewood is an evergreen bush 2 to 4 feet in height, with short stemlike fleshy leaves. It grows only on soils containing a large quantity of black alkali. It is found in the lower soils in the valley trough, where they are heavy in texture and receive and retain considerable moisture. Such soils have not been found to produce crops, and it is doubtful if the reclamation of such lands can be made profitable unless crops hitherto untried can be found to grow on them.

Saltbush never grows except when alkali is present in the soil. Two sorts are found—the bush or perennial and the weed or annual. The perennial saltbush is an ashen-gray colored bush, usually mistaken for sage brush. It can be readily detected by its seeds, which closely resemble those of the beet. It belongs, in fact, to another genus of the same family. Although this saltbush will grow in soils containing considerable black alkali, it prefers the white alkali—sodium chloride and sodium sulphate. Soils growing this bush are usually sandy loams for about 3 feet, underlain by heavier soil, in which the body of the alkali occurs. This land contains, as a rule, no hardpan or close water table and can be readily reclaimed by simply flooding to a considerable depth while irrigating crops. Shallow flooding or only surface wetting of such lands will soon carry the alkali to the surface in the form of a white crust.

Weed, or annual, *atriplexes* are sure indicators of alkali, but do not determine the kind, as they do equally well on soils affected with white or black. These weeds grow luxuriantly in free soils, usually of a sandy loam texture. These weeds are grayish green with a scurfy covering, the dust of which is very irritating to the nose. In height they range from  $1\frac{1}{2}$  to 4 feet. They indicate in most cases the lower limit of alkali (from 0.10 to 0.30 per cent) and it is usually found below the first or second foot of soil. Where these weeds do not occur over hardpan close to the surface, the land has been found to produce good barley and alfalfa and even vineyards and peach orchards. It should be handled very carefully in order to avoid capillary deposits of alkali in the surface from the accumulations usually found below. These lands yield readily to alkali reclamation by flooding and drainage.

Alkali heath is a perennial herb growing to a height varying from 1 to  $2\frac{1}{2}$  feet. This brush indicates the lower limits of alkali (0.10 to 0.30 per cent), and is found bordering large bodies of lands badly affected with either white or black alkali. Where this bush is found growing uniformly over an area to the exclusion of the more resistant alkali indicators, the alkali is found below the surface from 1 to 3 feet in a free sand or sandy loam soil. This land yields crops of alfalfa and grain or orchards and can be kept free from injurious quantities of alkali by proper methods of irrigation and drainage.

Little rabbit brush is a perennial composite bush about 18 inches high, with a sparse, smooth dark-green foliage. It grows in deep soils of a loamy texture with alkali in medium grades (0.30 to 0.50 per cent) or lower limits (0.10 to 0.30 per cent), usually sulphates. Such lands will admit of easy reclamation and should be very productive with proper irrigation.

Alkali weed, a yellow-flowered spiny-leaved composite, grows in a dense mass to a height varying from 2 to 8 feet, usually to the exclusion of other vegetation. It grows in either black or white alkali land in the lower (0.10 to 0.30) or medium (0.30 to 0.50) limits for alkali. It grows on sandy, sandy loam, and adobe soil equally well. It does not do well in soil with hardpan too close to the surface and prefers a soil with fair drainage. Where this weed grows grain crops are very spotted and are usually unprofitable. Alfalfa also does but poorly. It is unfit for vines and trees unless drained and the alkali removed.

Arrow, or irrigation, weed is a composite which grows in a single long straight stem 4 to 8 feet high with a brushlike head of leaves and flowers. It grows only in the lower alkali limits (0.10 to 0.30 per cent) in porous soils, generally after irrigation, and indicates a soil in which the alkali is not dangerous and may be gradually disappearing under irrigation connected with the naturally good drainage. The soils growing this weed are porous, deep, and generally well drained.

Salt grass is a short harsh grass very common in alkali lands. It will grow on all grades of soil and alkali, but does best in very salty soils above 0.50 per cent. Soils free from alkali are often found covered with it. It is thus a poor indicator of alkali conditions.

Foxtail, or barley grass, grows in considerable amount of alkali, or up to 0.50 per cent, because it sprouts and grows during the winter when alkali is not as harmful as in summer. Where foxtail grows well the soil is usually deep and rich and can be made to grow other crops profitably.

Slender water grass, or alkali grass, grows well during the summer season wherever water is allowed to stand for a time over alkali land, even with considerable amounts of black alkali present. This is the most nutritious native alkali-resistant plant at Fresno. It reseeds or plants itself without other culture or care than plowing and flooding in spring or summer. In reclaiming alkali soils by flooding, this grass gives considerable feed, both green and dry.

